



**Fermi National Accelerator Laboratory**

**FERMILAB-Conf-95/245-E**

**CDF**

# **Photon Plus Charm and Diphotons at $\sqrt{s}$ 1.8 TeV**

**R. Blair**  
**For the CDF Collaboration**  
*Fermi National Accelerator Laboratory*  
*P.O. Box 500, Batavia, Illinois 60510*

*Argonne National Laboratory*  
*9700 South Cass Avenue*  
*Argonne, Illinois 60439*

**July 1995**

Published proceeding of the *10th Topical Workshop on Proton-Antiproton Collider Physics*, Fermi National Accelerator Laboratory, Batavia, Illinois, May 9-13, 1995.



Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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# Photon Plus Charm and Diphotons at $\sqrt{s}$ 1.8 TeV

The CDF Collaboration  
Presented by Robert Blair

*Argonne National Laboratory  
9700 South Cass Ave.  
Argonne, IL 60439*

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The measurements of the charm plus photon and the diphoton cross sections are presented. They have been obtained from the CDF run 1a (1992-93) data using several different methods. The implications for Higgs detection at the LHC is discussed.

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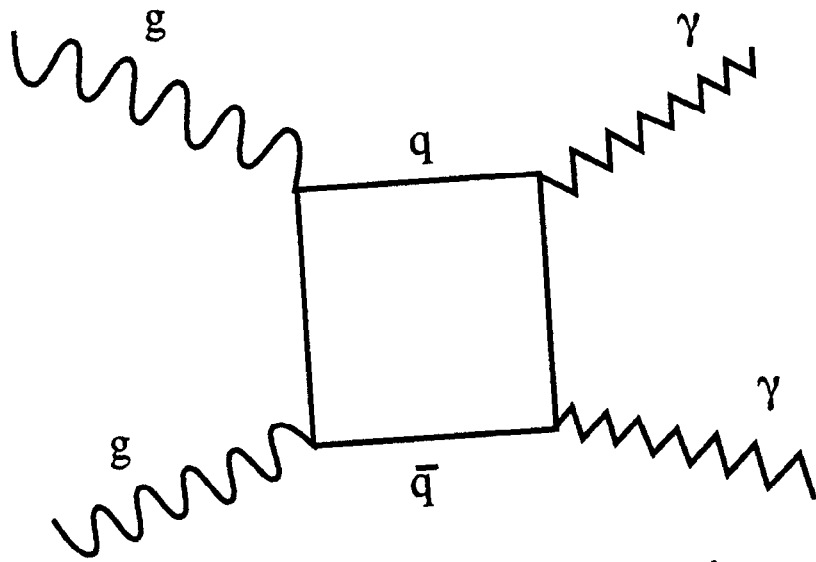
## INTRODUCTION

One of the most difficult measurements faced by the Large Hadron Collider (LHC) experiments is the attempt to observe the Higgs with a mass below 120 GeV/c<sup>2</sup> via the Higgs to two gamma decay. Current measurements from CDF and future ones made by both CDF and D0 should help in understanding the backgrounds to this difficult measurement. Estimates of the diphoton continuum which the Higgs mass bump will sit on at the LHC depend not only on the validity of the perturbative quantum chromodynamics (pQCD) calculations for diphoton production; they depend on the charm quark sea at low  $x$  and high  $Q^2$ . Several CDF measurements that check the current leading order (and next to leading order) calculations for both diphoton production and the charm sea are presented here.

At the Tevatron ( $p\bar{p}$  collisions at  $\sqrt{s} = 1800$  GeV) the production of diphotons is mediated by the two Feynman diagrams of figure 1. The two diagrams are expected to contribute significantly to the low  $E_T$  cross section for diphotons at the Tevatron and the LHC. The importance of the charm distribution for this measurement can be understood by observing that the first diagram's contribution to the cross section goes as the fourth power of the quark charge. The contribution of charm to this process will be sixteen times the  $d$  quark contribution, provided we ignore the relative difference in the size of the charm and  $d$  quark distributions themselves. This would be of little significance if the charm distribution was much smaller than the lower mass quark distributions. Figure 2 shows that this is not expected to be the case for the  $x$  and  $Q^2$  of interest.

All the measurements described here are from the data sample collected during 1992 and 1993 Tevatron collider run (approximately 20 pb<sup>-1</sup> of inte-

*a) Box diagram*



*b) Born diagram*

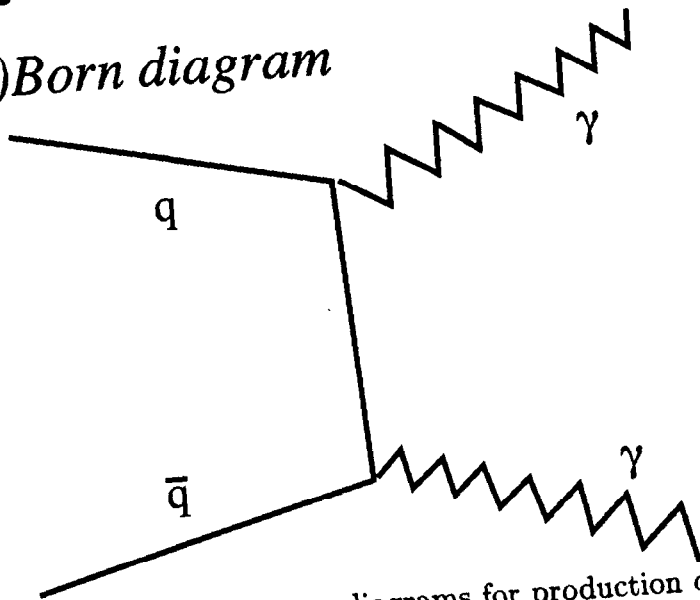
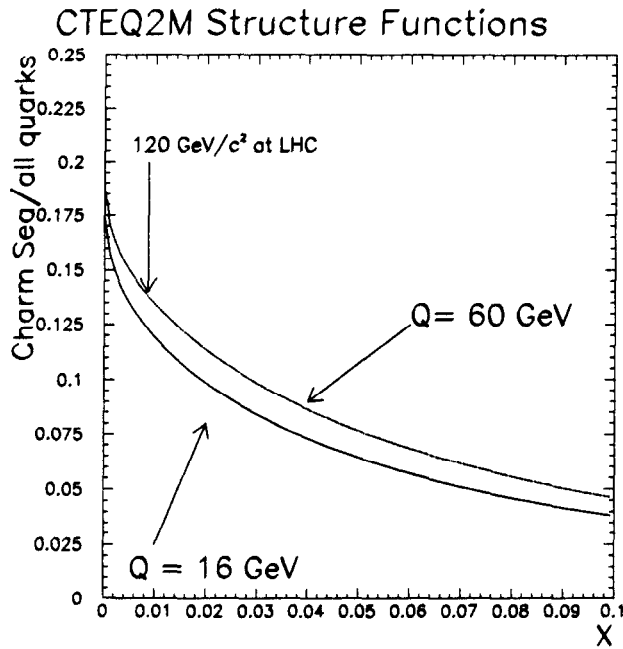


FIG. 1. Feynman diagrams for production of diphotons at lowest order.



**FIG. 2.** CTEQ2M structure functions showing the relative size of the charm sea compared to the light quark sea.

grated luminosity). The results are exclusively those reported by the CDF collaboration. In the near future both CDF and D0 should have results from the current collider run (representing roughly a factor of five increase in integrated luminosity) on many of the topics reported here.

### TEVATRON PHOTON PLUS CHARM PRODUCTION

Figure 3 shows the Feynman diagrams corresponding to photon plus charm production at the Tevatron. The dominant diagram (more than 80% of the cross section) is the first. Because of this the measurement of the cross section for a single isolated photon plus charm serves as a direct indication of the size of charm quark sea. The CDF collaboration has made several measurements of photons plus charm.

### Photon Plus Muon Production

One method of observing the photon plus charm production rate is to measure the cross section for events with an isolated photon plus a muon. The cuts on the photon candidates are the same as those applied for single photon measurements, see table 1. The muon cuts include a requirement that the tracks in the inner and outer muon chambers match with the central tracker track. The muons were required to have  $P_T > 4 \text{ GeV}/c$  and  $|\eta| < 0.6$ . In a sample of data that corresponds to  $15 \text{ pb}^{-1}$  of integrated luminosity there are 134 candidate events. The  $P_T$  distribution of the muons is plotted in figure 4

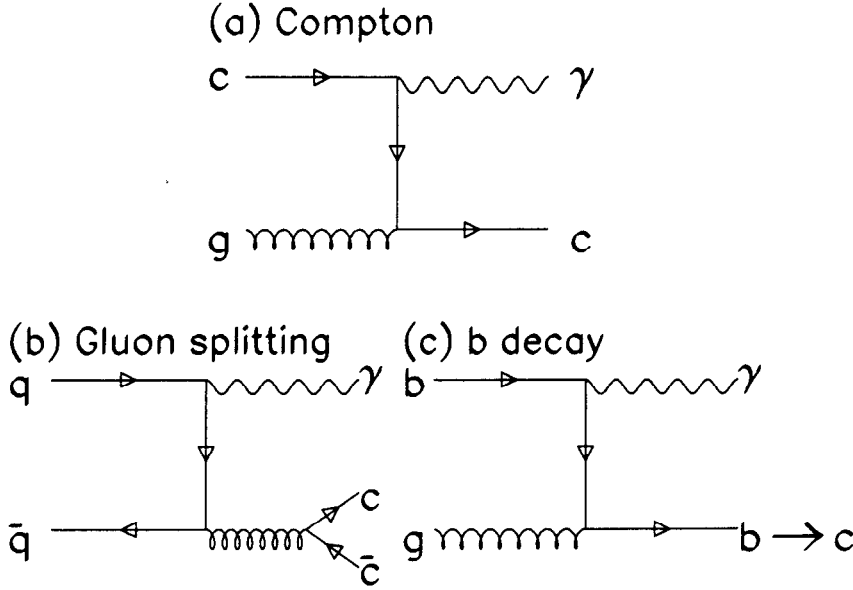


FIG. 3. Feynman diagrams that contribute to the photon plus charm signal at the Tevatron.

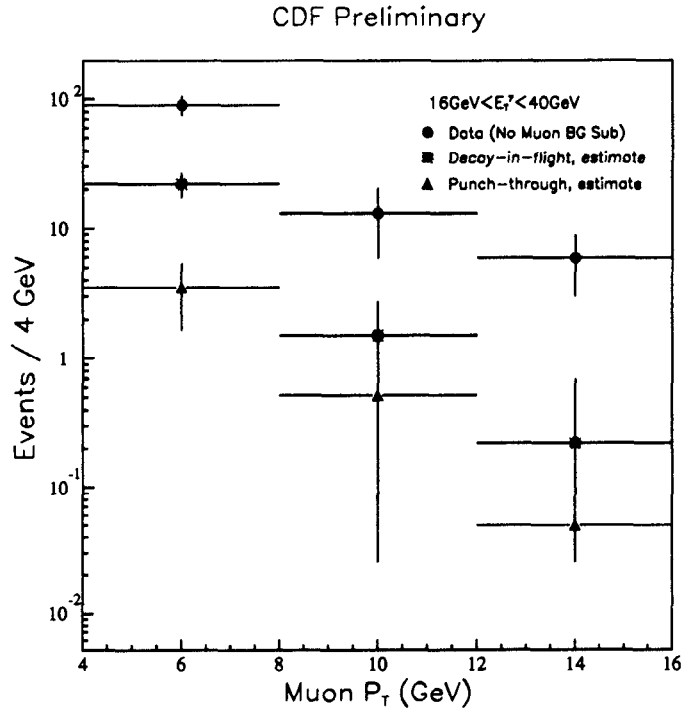
TABLE 1. Photon cuts for  $\gamma$  plus  $\mu$  sample.

	no track pointing at electromagnetic cluster	
	fiducial cuts on shower in electromagnetic calorimeter	
	1 GeV cut on extra clusters in EM cal. shower max.	
	loose cut on shower max. profile $\chi^2$ ( $\chi^2 < 20$ )	
	$E_T > 16$ GeV and $ \eta  < 0.9$	
	$E_T < 40$ GeV (to allow use of shower max. profile for bkg. evaluation)	
	$E_T < 2$ GeV in a cone (in $\eta, \phi$ space) of .7 around $\gamma$	

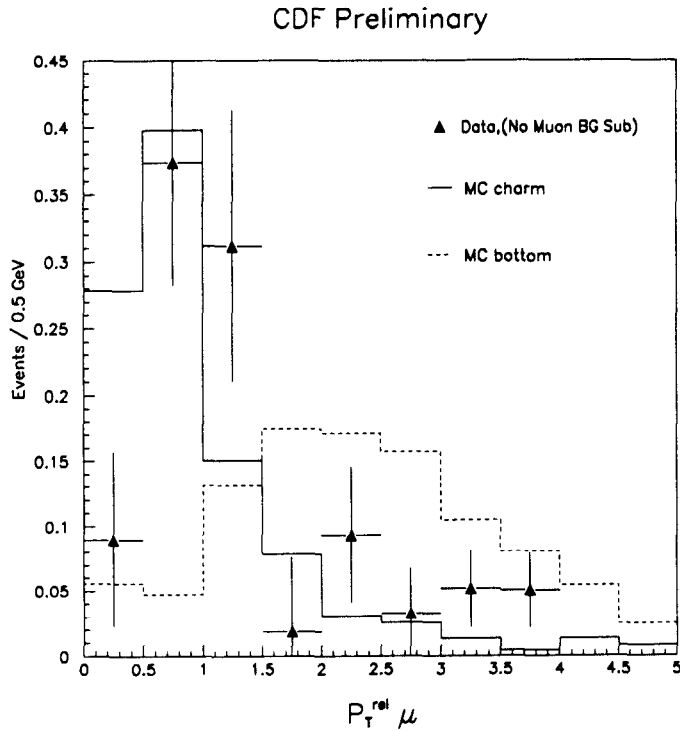
along with expected rates from muons produced by decay in flight of mesons prior to interaction in the calorimeter. Also the expected rate for mesons that exit the rear of the calorimeter and decay to muons that reach the second layer of muon chambers is indicated (labeled as *punch-through*).

An indication of the level of bottom contamination in the sample is given by figure 5. This plot shows the transverse momentum component of the muon candidates relative to the nearest jet axis. The data are more consistent with the expected distribution from charm than that due to muons from  $b$  decays. It should be understood that the contributions from *punch-through* and *decay in flight* muons have not been subtracted from this distribution (approximately 20%) and they are expected to resemble the charm distribution in this quantity.

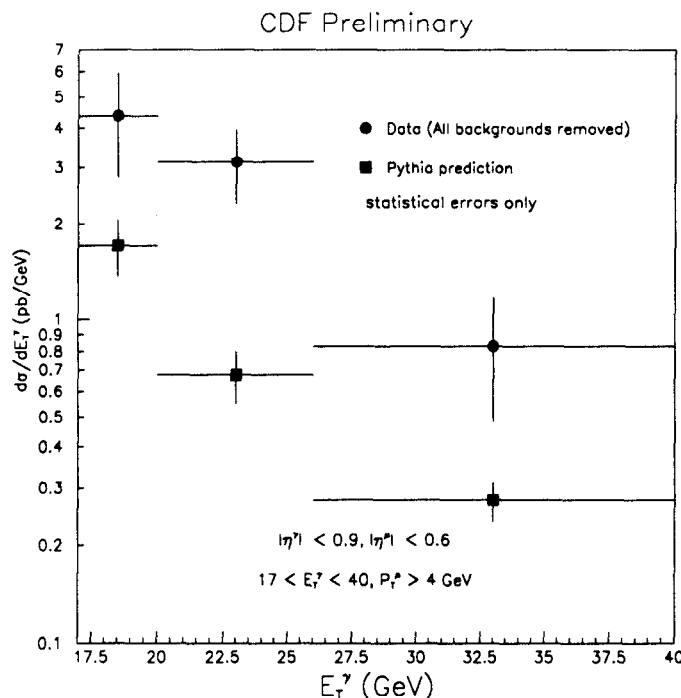
The final evaluation of the cross section requires subtraction of the non-photon (neutral hadron) contributions. This is done in the same way that



**FIG. 4.** The distribution of muon candidates observed in photon candidate events versus  $P_T$ . For comparison the expected rates for muon backgrounds are plotted.



**FIG. 5.** The distribution of muons  $P_T$  with respect to the axis of the nearest jet.



**FIG. 6.** The cross section versus photon  $E_T$  after subtraction of all backgrounds (events with non-prompt photons and fake muons). The corresponding PYTHIA cross section is also shown.

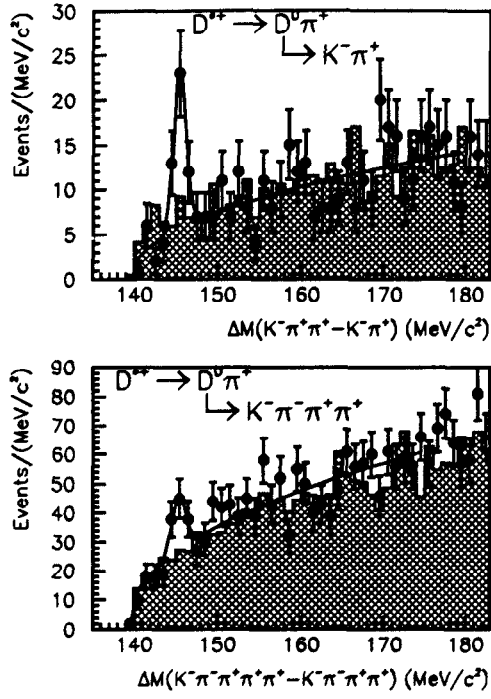
it is done for the single photon measurement reported elsewhere in these proceedings. The cross section, after subtraction of all muon and photon backgrounds, appears in figure 6. Plotted along with the data is the cross section from Pythia. As can be seen, the data are in excess of the Pythia prediction by roughly a factor of two.

### Photon Plus Charmed Meson Production

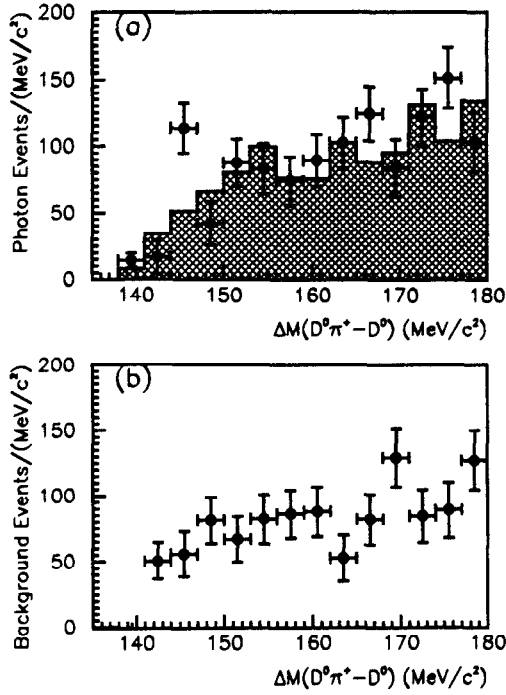
Another way to measure the photon plus charm production is to look for events with a high  $P_T$  photon and a charmed meson. The  $D^{*\pm}$  decay to a charged pion plus a  $D^0$  has a large branching ratio (68%) and the subsequent decay of the  $D^0$  to all charged particles either  $K\pi$ , branching ratio 4%, or  $K\pi\pi\pi$ , branching ratio 8.1%, have significant branching ratios. In a  $16.8 \text{ pb}^{-1}$  sample of events with isolated photon candidates (using the same cuts as described above) a clear  $D^{*\pm}$  peak can be reconstructed (see figure 7). To reduce combinatorics the tracks used to reconstruct this peak do not include tracks from reconstructed conversions,  $\Lambda$  and  $K^0_s$ . To assure understanding of the efficiency the reconstructed  $D^{*\pm}$  must have  $P_T > 6 \text{ GeV}/c$  and  $|\eta| < 1.2$  as well as cuts on individual track  $P_T$  values depending on the assumed identity ( $\pi$  or  $K$ ) of the particle it corresponds to. The  $K\pi$  ( $K\pi\pi\pi$ ) is considered to reconstruct to a  $D^0$  if the mass falls within a  $30 \text{ MeV}/c^2$  ( $20 \text{ MeV}/c^2$ ) window of  $1.8646 \text{ MeV}/c^2$ .

The evaluation of the number of photons in the sample is done using the





**FIG. 7.** The difference between the reconstructed  $D^0$  and the  $D^{*\pm}$  mass for photon candidate events and for two separate  $D^0$  decay modes.

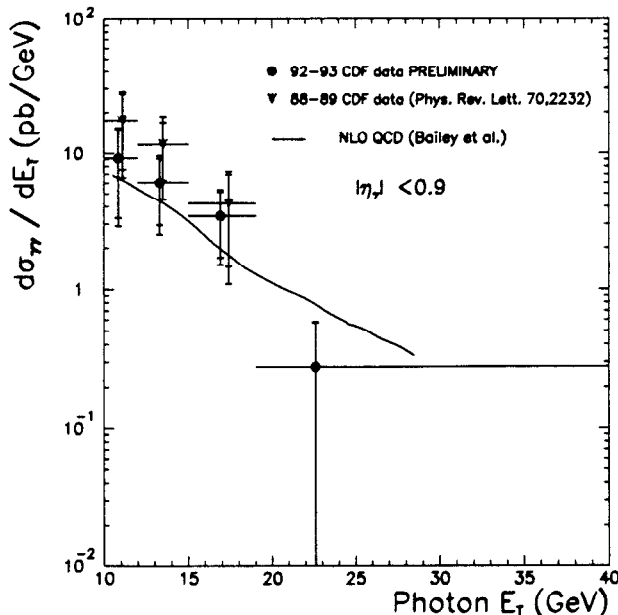


**FIG. 8.** The difference between the reconstructed  $D^0$  and the  $D^{*\pm}$  mass for photon events and for non-photon (background) events.

same technique as before. The mass difference distribution, figure 8, for photon and non-photon samples shows a prominent  $D^*$  signal in the photon sample but no such peak in the non-photon one. The number of events in the peak with  $D^0 \rightarrow K\pi$  ( $D^0 \rightarrow K\pi\pi\pi$ ) after subtracting non-photon events is  $41.4 \pm 10.3$  ( $72.0 \pm 15.8$ ) on a combinatoric background of  $11.5 \pm 3.0$  ( $40.1 \pm 3.0$ ). The efficiency for reconstructing the  $D^{*\pm}$  is  $0.150 \pm 0.024$  ( $0.067 \pm 0.011$ ) as evaluated by a detailed montecarlo simulation. Using the efficiency and combinatoric background estimate a cross section for photon plus  $D^{*\pm}$  production of  $0.48 \pm 0.15^{+0.07}_{-0.08}$  nb. is obtained. This is to be compared to a cross section from PYTHIA of 0.211 nb. (using  $Q = P_T$  and CTEQ2M structure functions).

## DIPHOTON PRODUCTION

The diphoton production cross section is measured by CDF in two ways. For the low energy end of the spectrum the method used to subtract background from single photon samples is extended to the two photon case. This method is unworkable at higher  $E_T$  since it requires fairly tight cuts and introduces unacceptable losses in an already small data sample. For the higher mass end of the spectrum the event rate is plotted (without subtraction of the non-photon contribution) and an estimate (based on the single photon data sample) of the background is added to the theory to show the expected rate for pQCD plus background.



**FIG. 9.** The diphoton cross section versus  $E_T$  (each event is entered twice in this distribution, once for each photon). The inner errorbars are statistical the outer are systematic.

Figure 9 shows the cross section versus photon  $E_T$  (each event counts twice in this plot, once at the  $E_T$  of each of its two photons). The method used

to extract the photon-photon contribution as distinct from the background contribution is essentially identical to the method described in reference (1). The photon candidate cuts are the same as those listed above except that the  $E_T$  cut is  $E_T > 10$  GeV and one of the two photon candidates may have up to 4 GeV in a cone of .7 (in  $\eta, \phi$  space) around it. For candidates above 35 GeV in  $E_T$  the preshower pulseheight is used instead of the lateral profile measured at shower maximum to distinguish between background and photons (4). The results for the 12.8 pb<sup>-1</sup> luminosity 1992-1993 data set is compared to the data from the 1988-1989 run (1). Both data sets are reasonably consistent with the NLO QCD prediction (2).

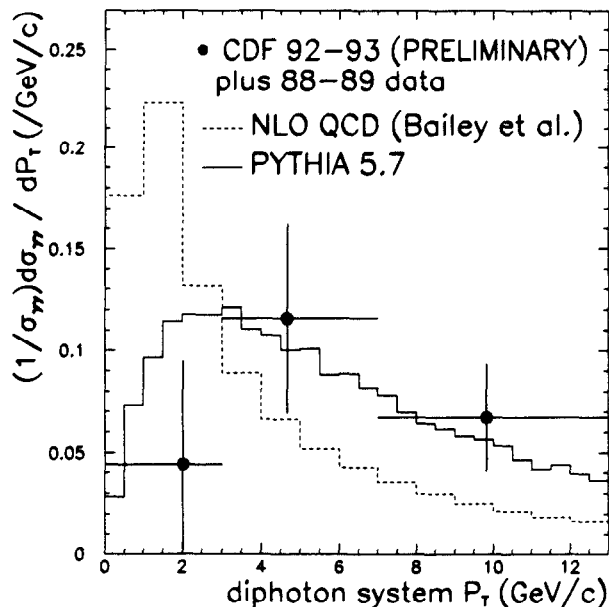


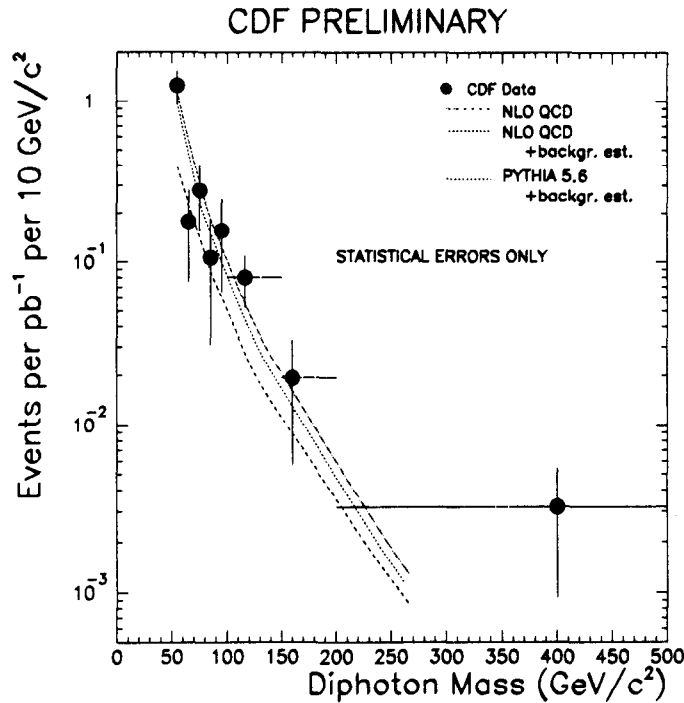
FIG. 10. The distribution in diphoton system  $P_T$  using both data samples (1989-90 and 1992-93).

One quantity of interest that can be measured using the low  $E_T$  diphoton sample is the distribution of the diphoton system  $P_T$ . This is a measure of how much the hard scatter, which produces the two photons, is boosted by initial and final state soft gluon emission. Figure 10 shows the measured distribution along with the predictions of the NLO calculation and the PYTHIA monte-carlo. The NLO QCD prediction clearly underestimates the effect of this smearing, while PYTHIA appears to agree reasonably well.

Figure 11 shows the event rate versus diphoton mass for candidate events. The candidates are defined by loose cuts listed in table 2. The method of evaluating the background is described in (3).

**TABLE 2.** Cuts applied to high  $E_T$  diphoton sample.

$E_T > 18\text{GeV}$ 2 central electromagnetic clusters ( $\eta < 0.9$ )
fiducial cuts for both clusters
number of 3d tracks $< 2$ (if one then $P_T < 2\text{GeV}$ )
$E_T$ around the clusters ( $\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.7$ ) less than 10% of cluster $E_T$
$ Z_{\text{vertex}}  < 60\text{cm}$



**FIG. 11.** The event rate versus diphoton mass for the 1992-93 run compared to various calculations. The theory has been multiplied by the correct factors (acceptances) to yield a sensible comparison.

## CONCLUSIONS

The measurements that can be made at the Tevatron to indicate how well we know the backgrounds to Higgs to gamma gamma, show that current calculations tend to underestimate the irreducible gamma gamma contribution to the background.

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